IMPACT OF MASK STACK ON HIGH NA EUV IMAGING

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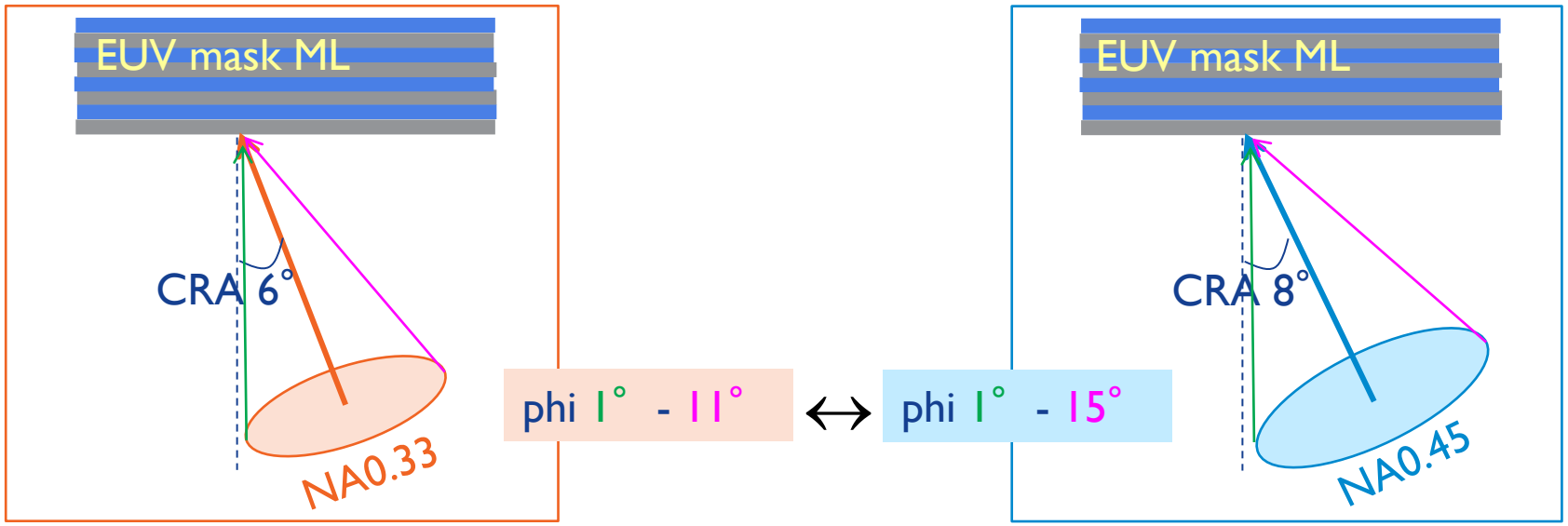
INTRODUCTION

Increasing NA beyond 0.33 at reduction ratio 4X

- Angular range at mask side increases



Impact on

- Reflectivity (multilayer and absorber)
- Diffraction (intensity and phase)
- Imaging (contrast and pattern shift through focus)

Can mask stack tuning help?

ML = MultiLayer
CRA = Chief-Ray Angle

INTRODUCTION

Increasing NA beyond 0.33 at reduction ratio 4X

- Rigorous lithography simulations assess impact of high NA on EUV imaging
- Good description of 3D mask stack in simulator required
- Benchmark to current mask stack through experimental validation

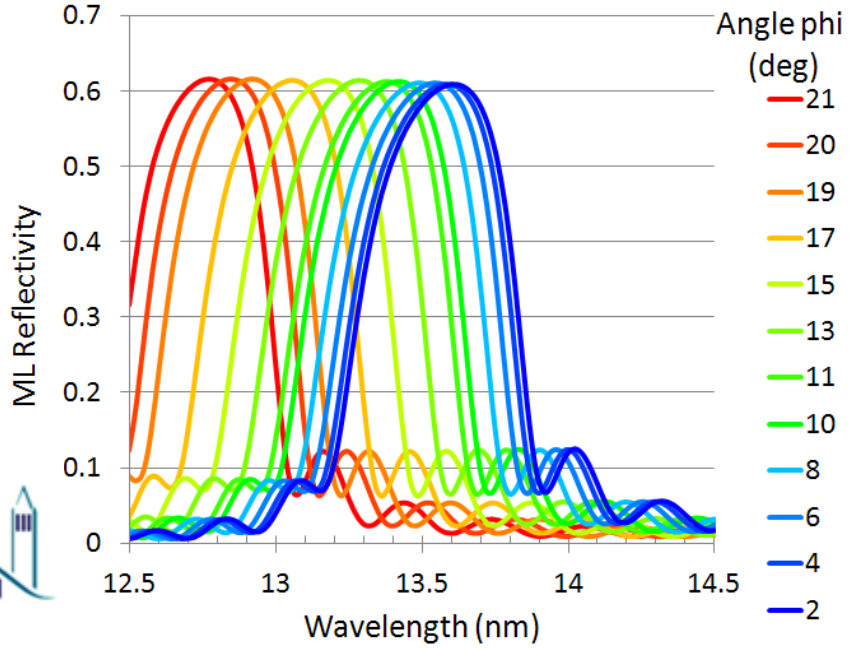
OUTLINE

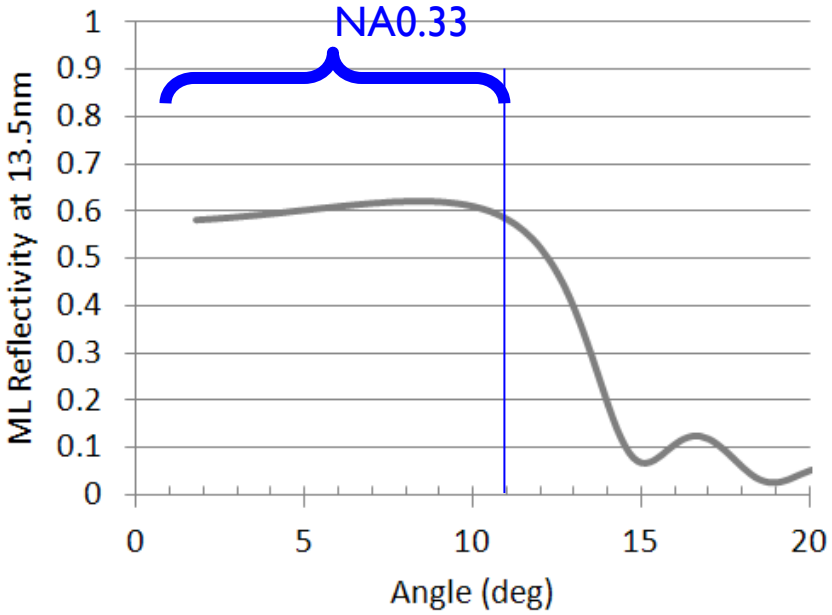
- ML definition
  - Reflectometry on current EUV mask
- Absorber definition
  - Reflectometry on current EUV mask
  - Mask design & measurements
  - Diffractometry on current EUV mask
- Imaging at NA0.45 4X reduction
  - ML tuning
  - ML impact on imaging
  - Absorber impact on imaging
- Summary & Conclusion

In this presentation: Reduction ratio is always 4X

EXPERIMENTAL ML REFLECTIVITY
THROUGH WAVELENGTH AND INCIDENCE ANGLE

- ML reflectivity measured in clear areas of 5x5mm² on 51nm Ta-based mask
- at LBNL reflectometer beamline for EUV



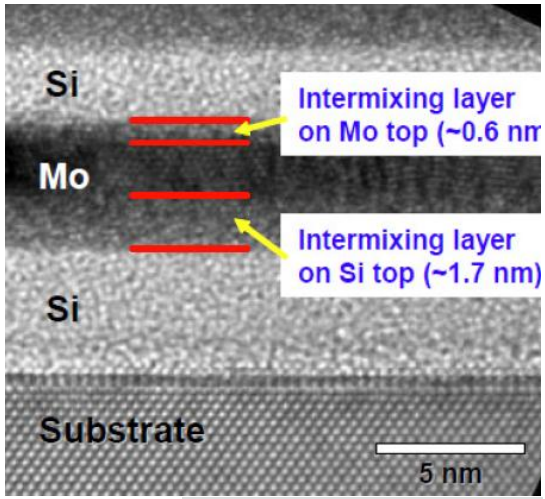


- Uniform over NA0.33
- Experimental peak ML Reflectivity below 0.65

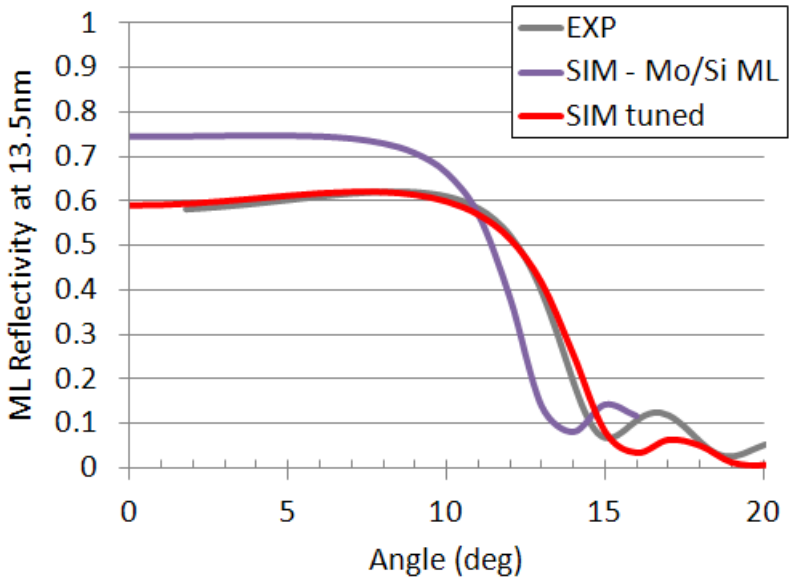
- Current ML blank has good reflection control for NA up to 0.33

ML DEFINITION IN SIMULATOR
FITTED TO EXPERIMENT AS ML WITH INTERMIXING

- In simulator we assumed until now ML consisting of 40 repetitions of Si/Mo layer with perfect interface
- From literature* we know intermixing at the interfaces will occur
- Experimental reflectometry as input for fitting mask ML in simulator



* Seo *et al.*, SPIE2007



- Definition in simulator = ML with intermixing
  - fitted to mimic experimental measurement on ML blank

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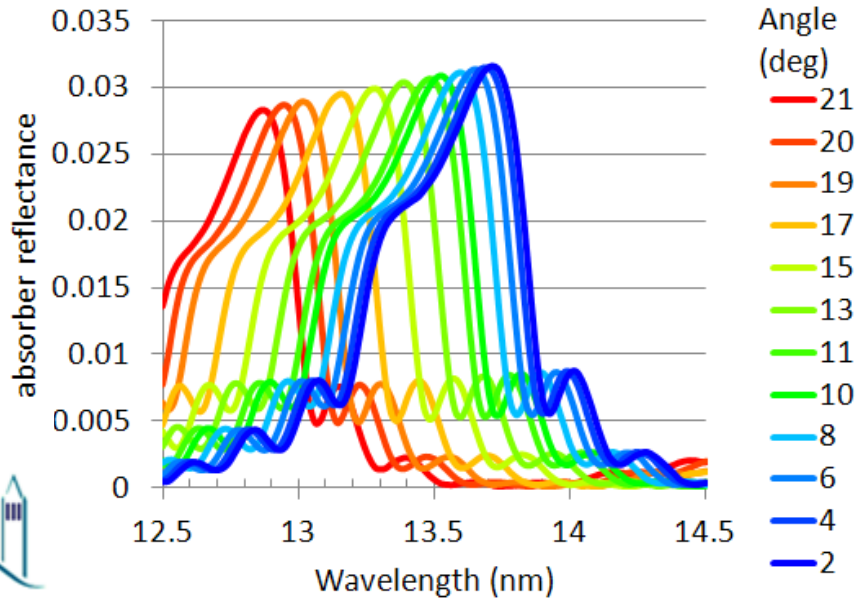
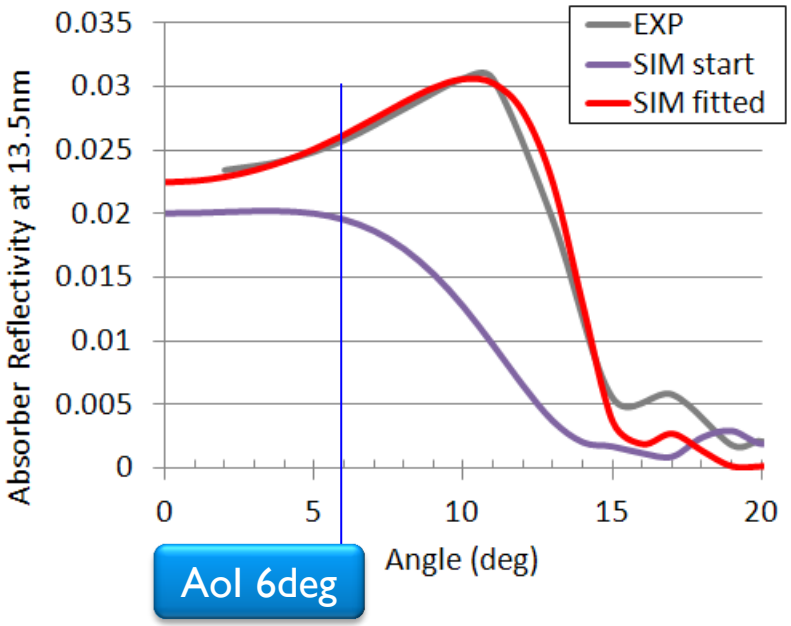
MASK ABSORBER REFLECTIVITY
THROUGH WAVELENGTH AND INCIDENCE ANGLE

- **Absorber** reflectivity measured on 51nm Ta-based mask
- at LBNL reflectometer beamline for EUV





- Absorber definition in simulator using CXRO n&k is good starting point
- Absorber definition in simulator can be fitted to experimental reflectivity by thickness and n&k fitting

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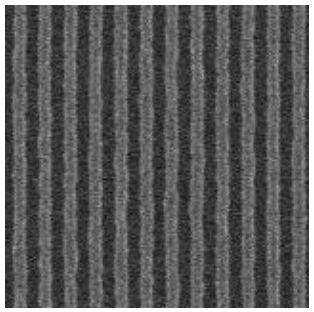
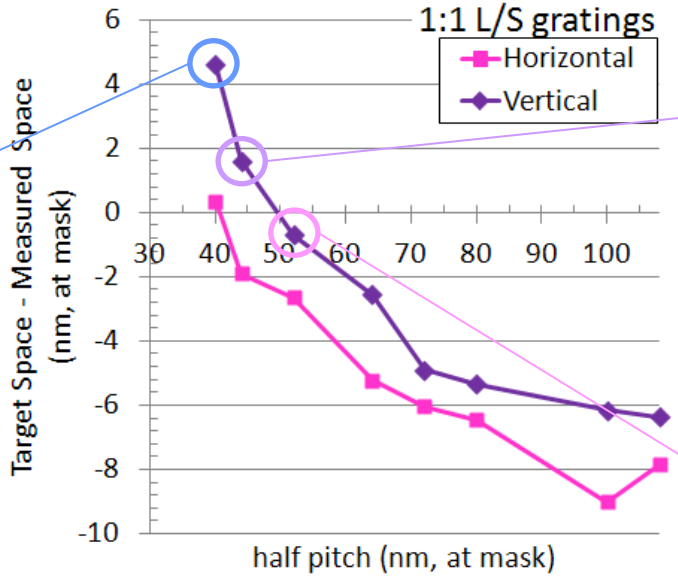
DIFFRACTOMETRY MASK

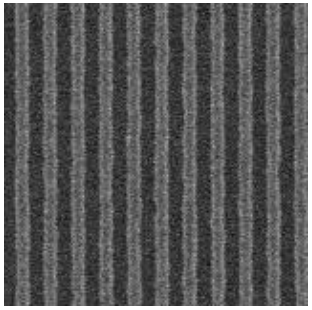
- Mask has 51nm Ta-based absorber
- Diffractometry L/S gratings



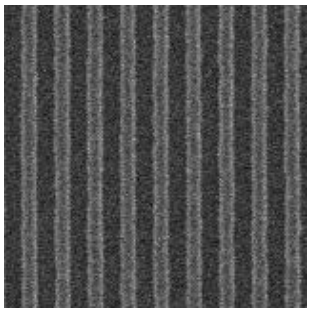
40nm 1:1 (at mask)
i.e., 10nm LS at 1X

Mask topdown SEM images





44nm 1:1
(at mask)
i.e., 11nm LS
at 1X



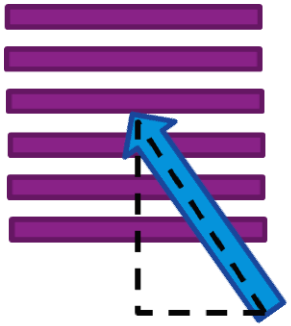
52nm 1:1
(at mask)
i.e., 13nm LS
at 1X

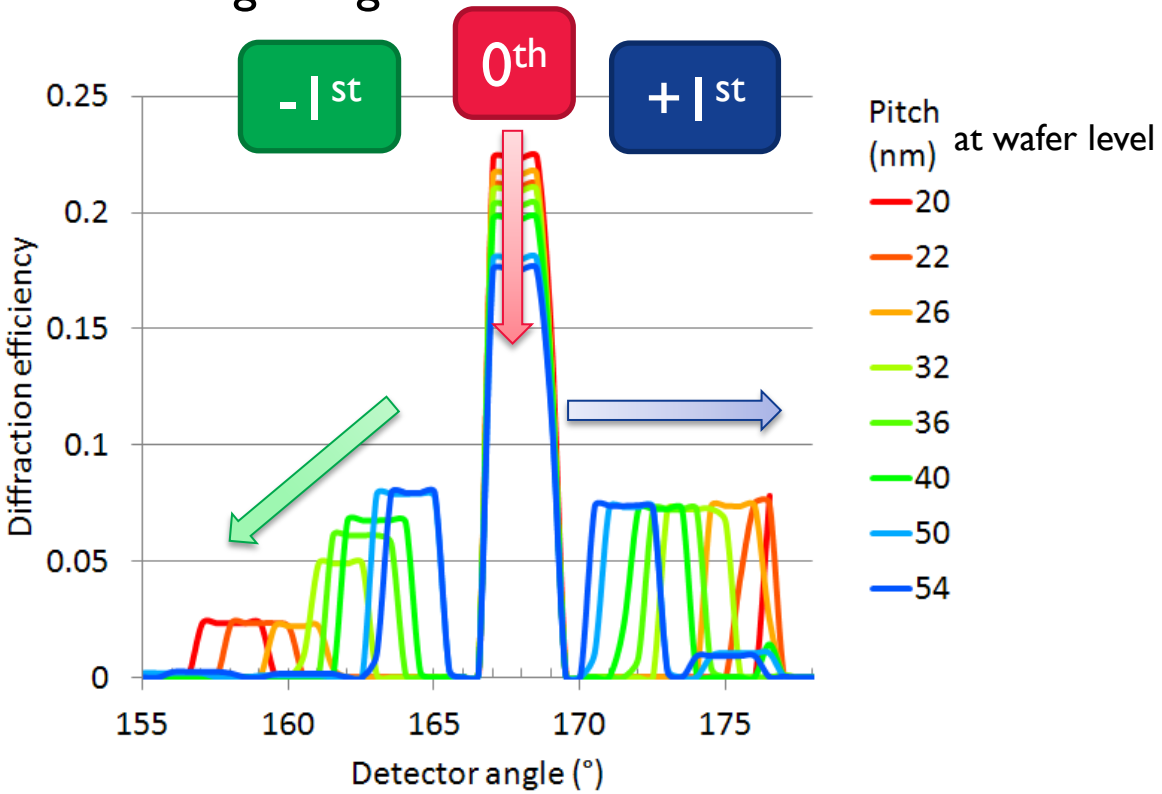
- Mask CD measurements from top-down CD SEM well documented
- Resolution down to 10nm hp (1X) over full field !

AoI 6deg

DIFFRACTOMETRY
SPECTRA OF 1:1 HORIZONTAL LS

"1:1" LS - **Horizontal** orientation only
Beam incident perpendicular on grating



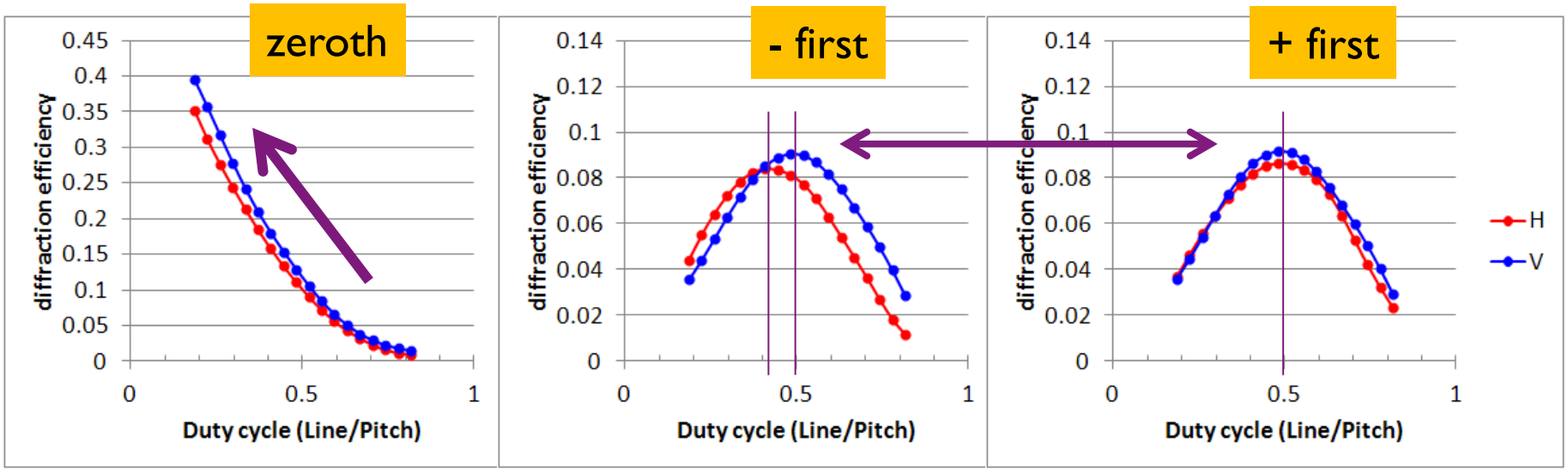


- 0th order decreases with increasing pitch
- -1st order drops with decreasing pitch ⇒ absorber shadowing effect

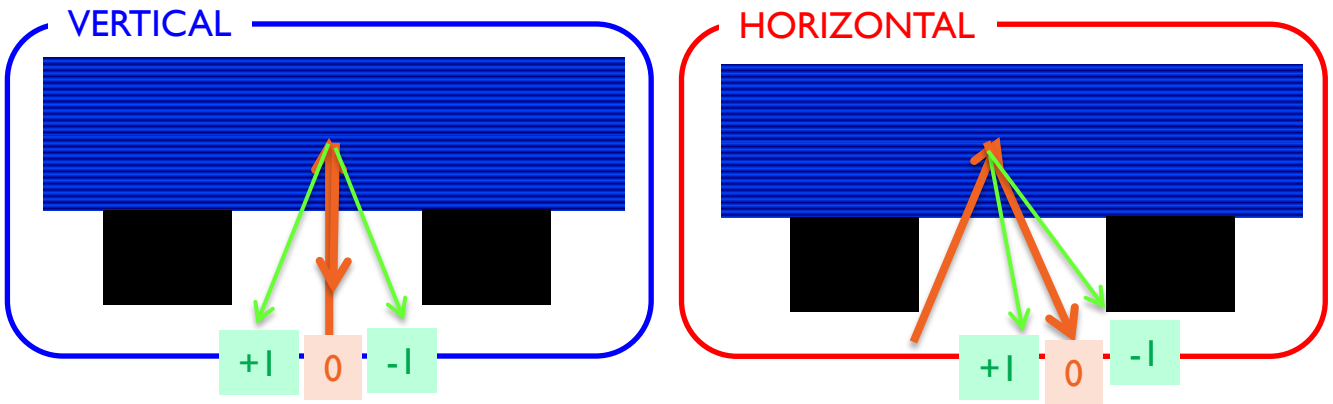
AoI 6deg

DIFFRACTION SIMULATION

IMPACT OF SPACE WIDTH FOR 54NM PITCH



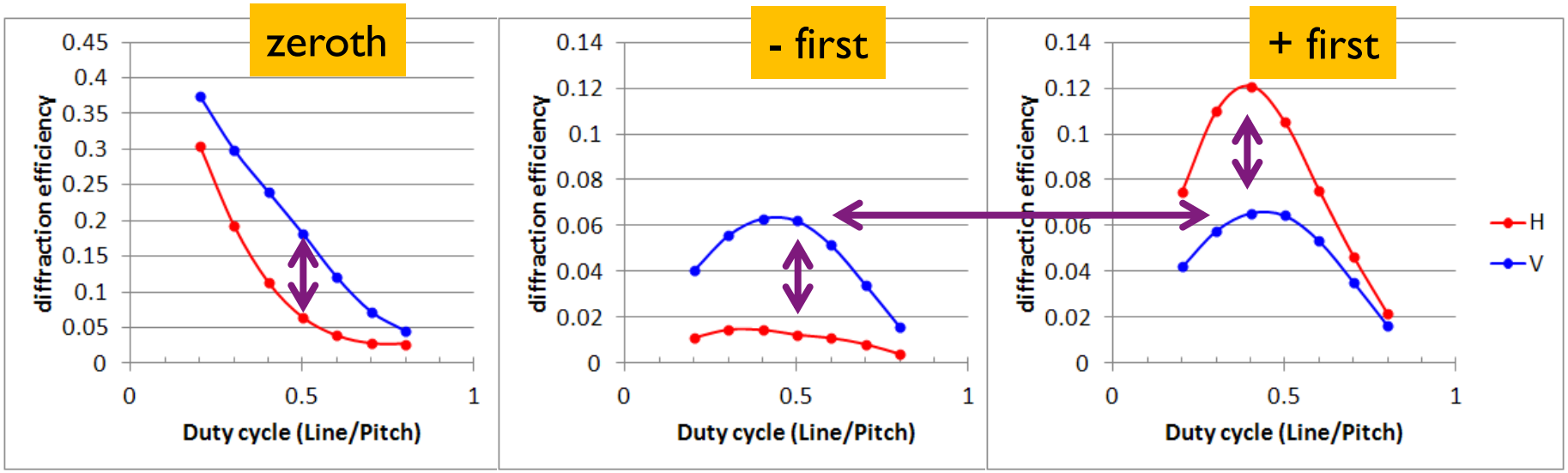
- Zeroth order increases with decreasing mask line width
- Horizontal orientation suffers from shadowing



AoI 6deg

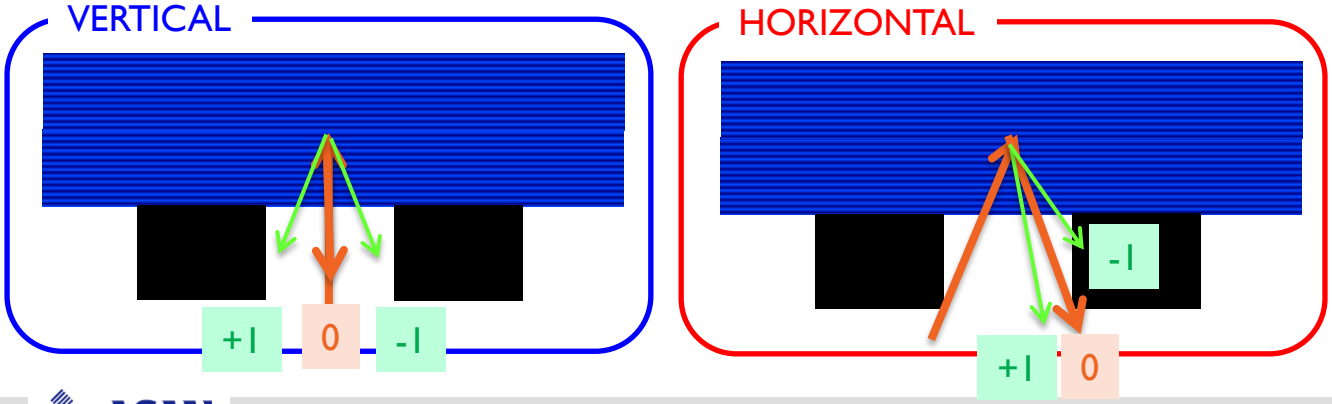
DIFFRACTION SIMULATION

IMPACT OF SPACE WIDTH FOR 20NM PITCH



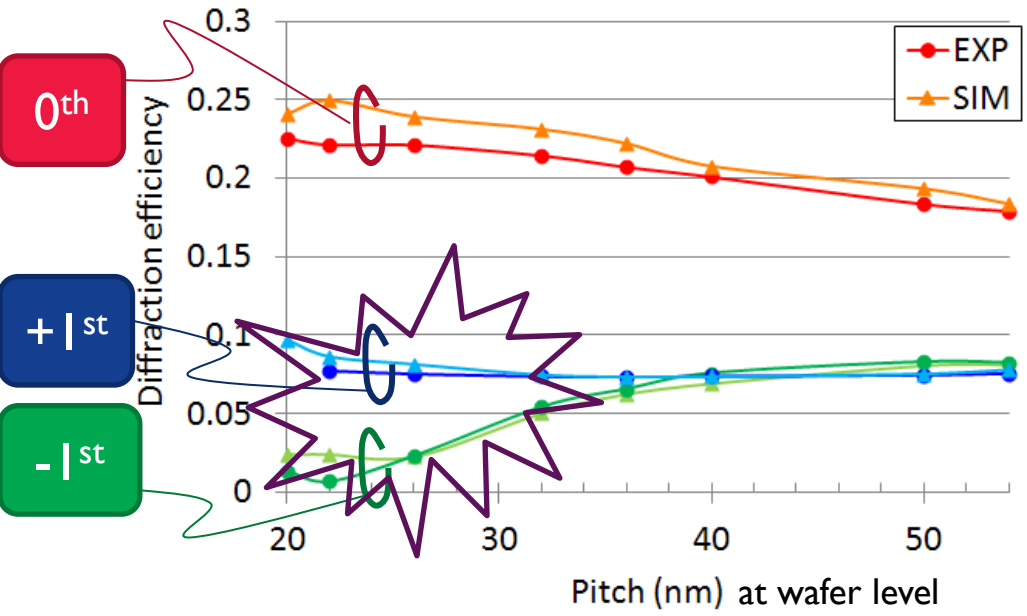
Severe shadowing (i.e., 3D mask effect) for small pitches:

- Vertical orientation : both first orders are impacted
- Horizontal orientation : minus first order gets blocked



AoI 6deg

DIFFRACTOMETRY OF 1:1 HOR. LS
CORRELATION EXPERIMENT & SIMULATION



Simulated diffraction (using fitted mask stack definition) needs only one fixed CD-offset for all mask line widths to get **good correlation** with experimental diffraction

- Fitted mask stack definition in simulator allows interpretation of experimental diffractometry
- Patterned absorber at small spaces is responsible for imbalanced diffraction pupil → causing asymmetric shadowing and pattern shift through focus

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- Imaging at NA0.45 4X reduction
  - ML tuning
  - ML impact on imaging
  - Absorber impact on imaging
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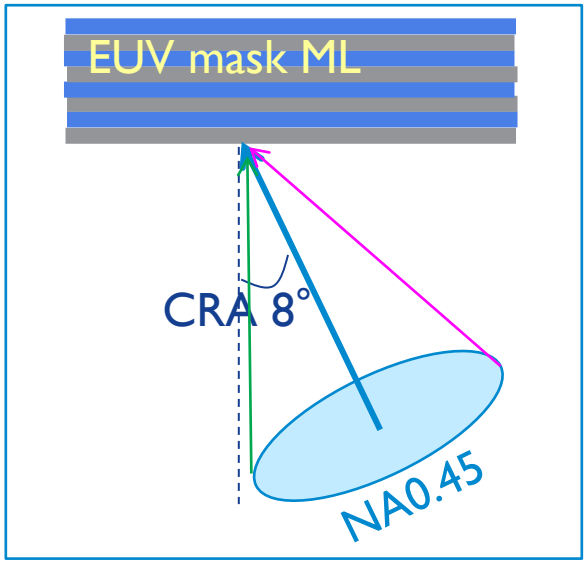
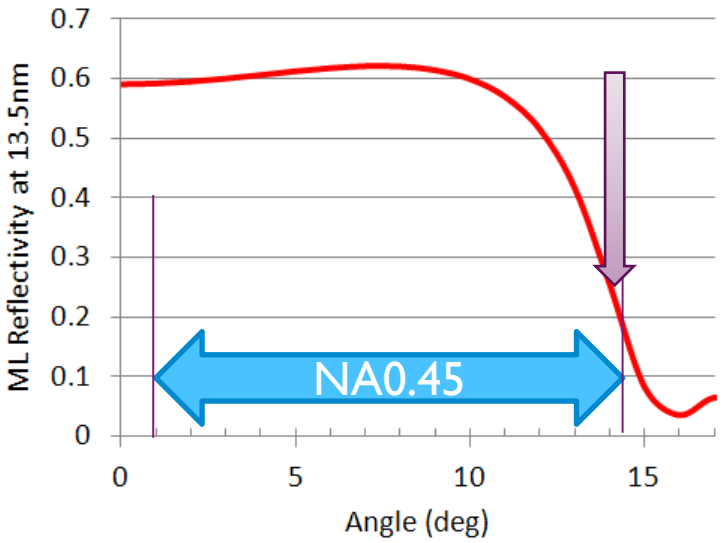
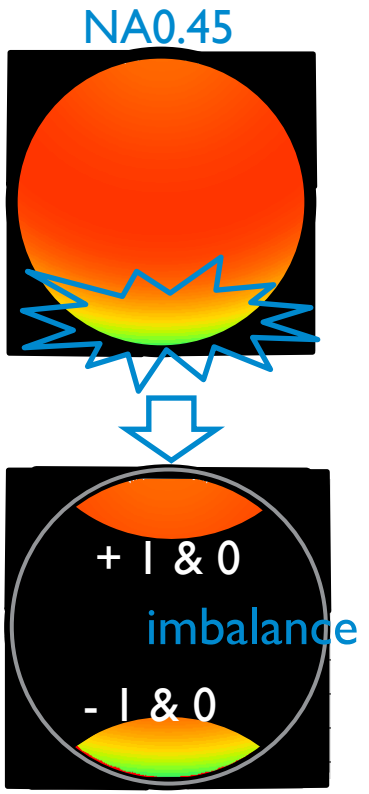
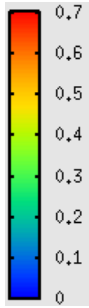
IMAGING SIMULATION AT NA0.45 4X
CURRENT ML INDUCES IMBALANCE

- Increasing NA and CRA increases angular range on mask
- ML reflectivity:



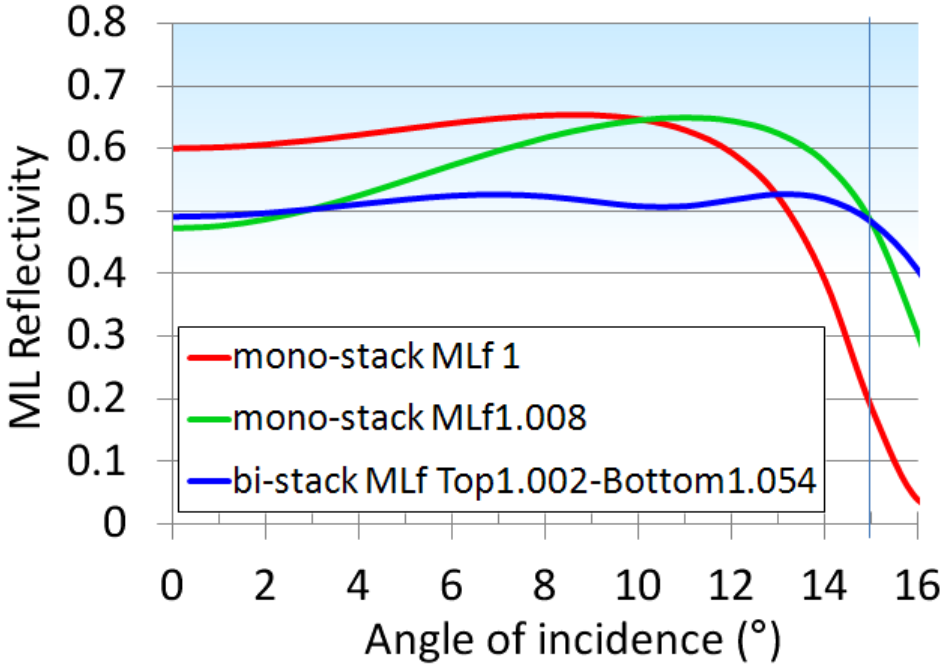




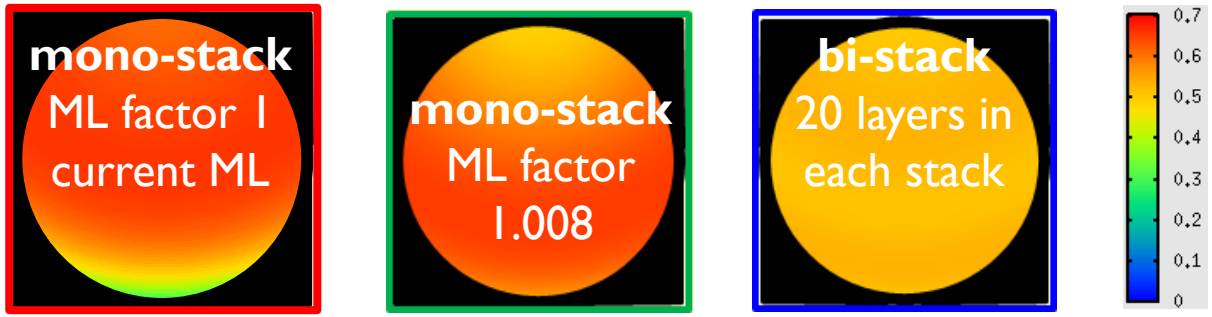


- Current ML: sharp reflectivity drop beyond 12° incidence angle is captured by NA0.45 ⇒ causing diffraction imbalance
- Compensate reflectivity by adjusting periodicity by ML factor

ML TUNING
FOR UNIFORM REFLECTIVITY WITHIN NA0.45



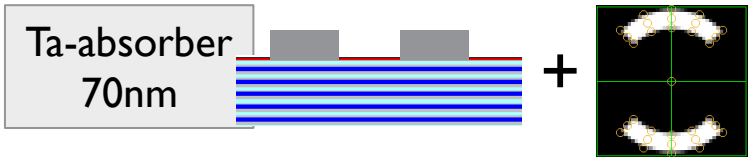
EUV ML reflectivity within NA0.45 at CRA 8deg 4X

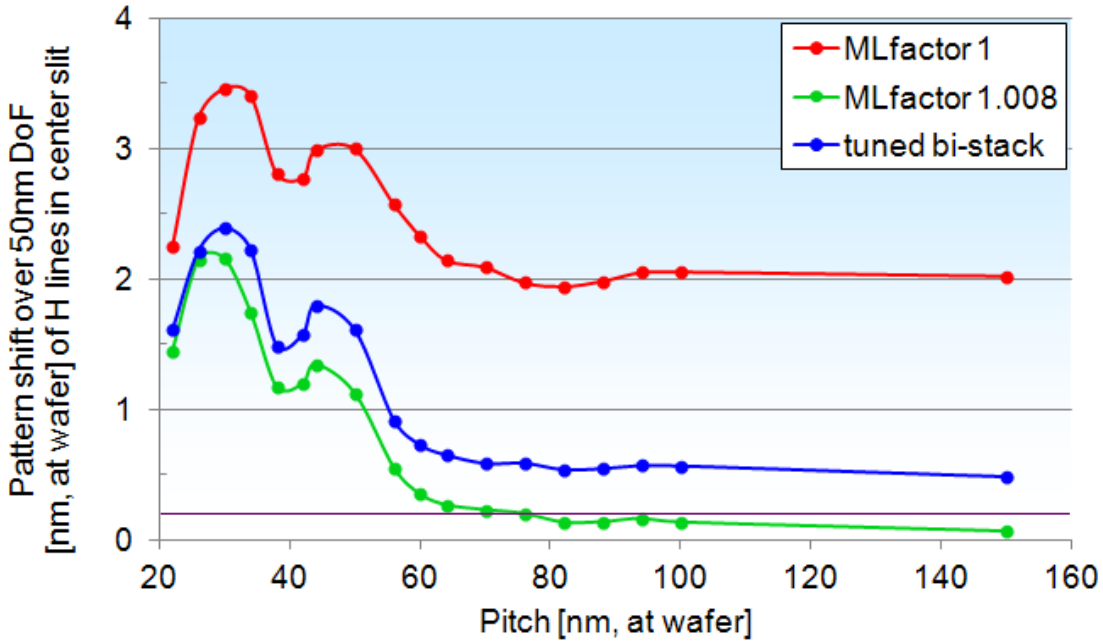


- Bi-stack can give uniform reflectivity through large angles

ML IMPACT ON IMAGING AT NA0.45
PATTERN SHIFT THROUGH FOCUS

L/S imaging through pitch : Dipole90° σ0.74/1
at NA0.45 CRA 8° 4X reduction

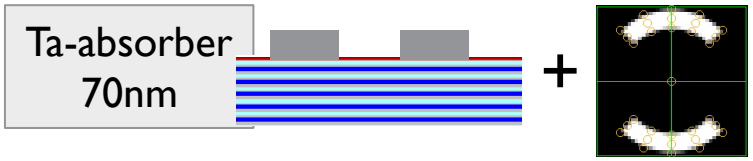




- Pattern shift through focus can be reduced by tuning ML, but significant pattern shift remains in small-pitch region.

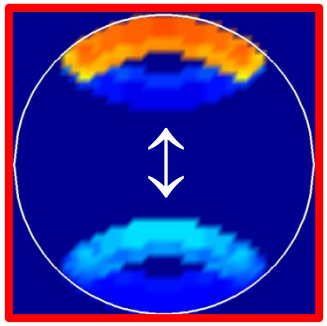
ML IMPACT ON IMAGING AT NA0.45
PUPIL FILLING

L/S imaging through pitch : Dipole90° σ0.74/1
at NA0.45 CRA 8° 4X reduction

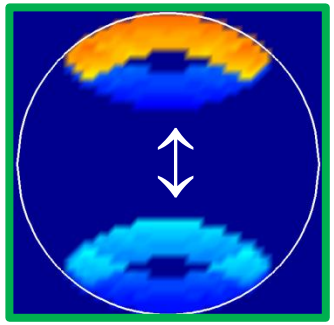


Pupil filling for 11nm L/S at NA0.45:

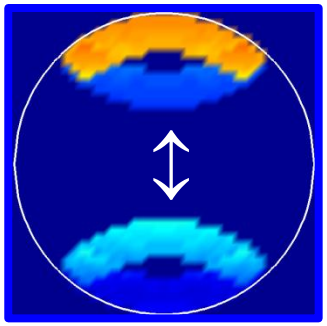
mono-stack
ML factor 1
current ML

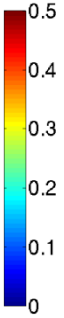


mono-stack
ML factor
1.008



bi-stack
20 layers in
each stack

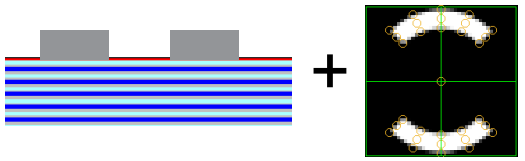


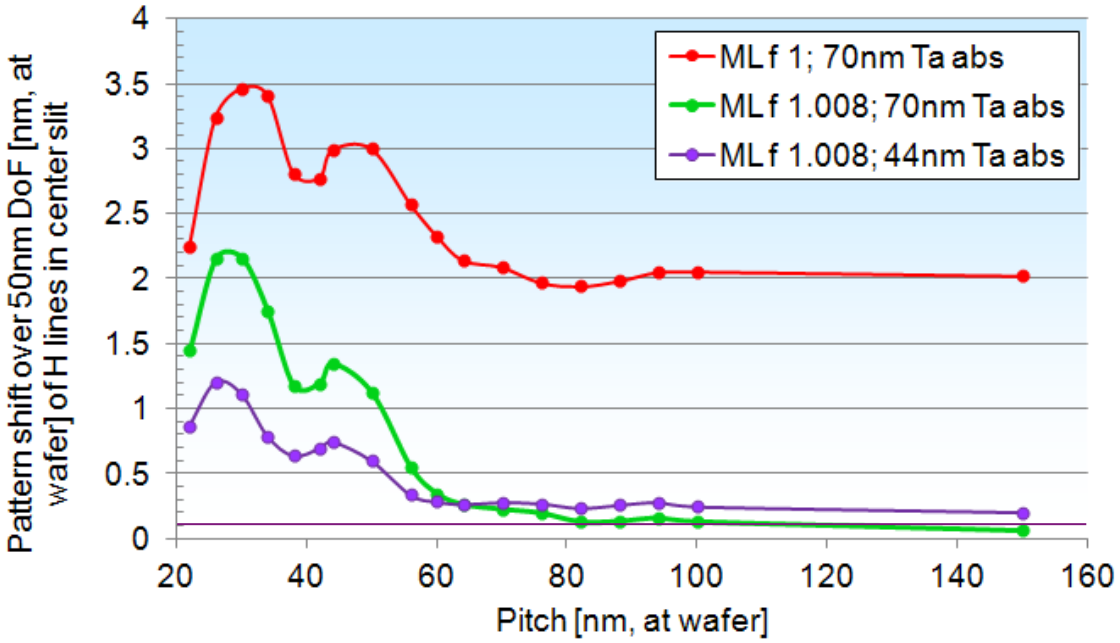


- Imbalance in diffraction pupil remains after ML tuning
  → Absorber impact at high angles, as shown by diffractometry

ABSORBER & ML IMPACT
PATTERN SHIFT THROUGH FOCUS

L/S imaging through pitch : Dipole90° σ0.74/1
at NA0.45 CRA 8° 4X reduction





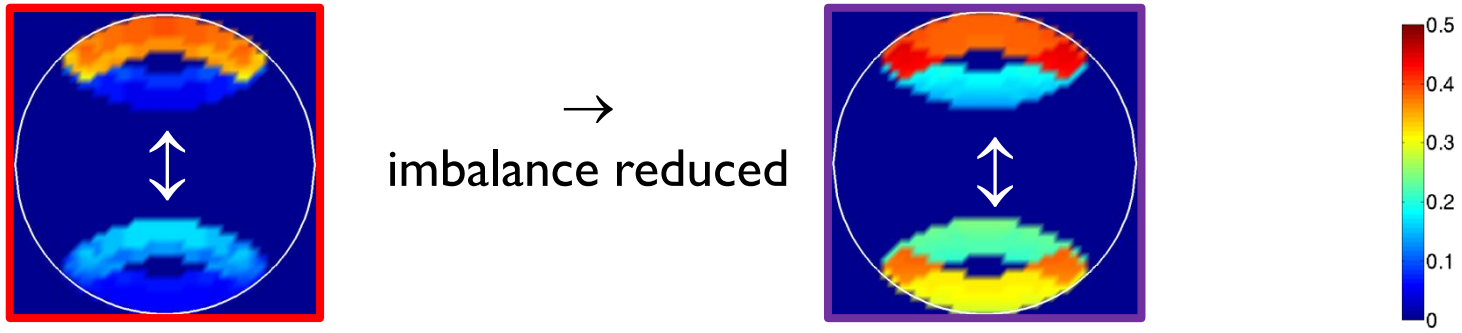
- Pattern shift through focus can be further reduced by tuned ML and thinner absorber, but not to acceptable level.

→ large angles at mask remain issue in small-pitch region

ABSORBER & ML IMPACT
UNDERSTANDING AT SMALL PITCH

Geometrical visualisation at small pitch

Pupil filling for 11nm L/S at NA0.45 CRA8° 4X reduction:



- Combined ML and absorber tuning helps reducing EUV-specific issues such as pattern shift through focus,

but strong mask effects remain in small-pitch region due to large angles.

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SUMMARY & CONCLUSION

Experimental assessment of current mask stack

- Fitting of mask stack (ML + absorber) in simulator to actual mask performance
  - based on reflectometry and diffractometry measurements
- ***Experimental validation*** of patterned absorber impact on diffraction and predicted by simulation

Imaging simulation at NA0.45 CRA8° 4X reduction

- ***No solution*** found yet that balances imaging performance due to complex interplay of large angles and mask stack (ML and absorber)

Outlook for high NA EUV

- ***Reduce mask effects*** (smaller range of incidence angles on mask) by
  - CRA $\leq 7°$ cf. previous talk of JT Neumann (Zeiss)
  - higher Reduction ratio
- Explore other tuning options
  - illumination tuning

"Thank you" to
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ASPIRE
INVENT
ACHIEVE

DNP

SYNOPSYS 25 Years

ASML

BERKELEY LAB

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